Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**
4. TITLE AND SUBTITLE **Application of Autonomous Underwater Vehicle Systems in Distributed Ocean Observing Networks**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Oceanographic Office,1002 Balch Blvd,Stennis Space Center,MS,39522-5001**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002176. Presented at the MTS/IEEE Oceans 2008 Conference and Exhibition held in Quebec City, Canada on 15-18 September 2008.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Application of Autonomous Underwater Vehicle Systems in Distributed Ocean Observing Networks

Doug Cronin, G.W. Landrum, Ken Sharp
Naval Oceanographic Office
1002 Balch Blvd.
Stennis Space Center, MS 39522-5001

Abstract-**The task of characterizing a volume of ocean, seafloor, and/or sub-seafloor has long been the realm of (1) surface vessels using hull-mounted sensors or uniquely configured tow bodies, (2) free floating/drifting systems, and (3) moored sensors. In the last decade, Autonomous Underwater Vehicles (AUVs) have emerged as a viable and efficient means for the complex tasks of oceanographic data collection and seafloor mapping efforts that enable an accurate volume depiction. Geophysical and telecommunication survey companies have also demonstrated the cost-effectiveness of these systems, as evidenced by the growth in commercial inventory to support pipeline or cable route studies. The high operational tempo of these systems is further proof of this growth. Additionally, a broad spectrum of joint government and academia partnerships has sponsored efforts across the globe to develop permanent ocean observing systems in coastal environments. Such systems consist primarily of sensor nodes that are moored in a fixed location and connect to each other and/or a relay node (ocean to surface/land) via a fiber-optic subsurface Ethernet network.**

As seafloor observing systems move into the deeper water environments, installation costs for fiber networking present fiscal and technical challenges. The application of AUV systems as a mobile node in such networks presents an opportunity for expanding the basic data-mapping mission. This paper discusses efforts to date and elaborates on concepts for integrating AUVs into such networks for the purpose of data recovery, relay, and transfer between other moored, drifting (i.e., profiling floats, gliders), or surface network nodes.

I. Introduction

The subject of ocean observing systems has dominated the scientific research community and has taken hold on many fronts. Although these systems have existed in various forms for several years (and are described later in this document), a number of environmental phenomena have sparked accelerated investment and commitment by governments to design and install robust and linked observing networks that will allow unprecedented visibility into the ocean realm. The phenomena include global climate change, ocean dynamics, and seismic activity. These network efforts have taken hold in many areas of the world and are motivated by the desire to (a) learn and understand the complex processes and (b) apply such knowledge to become better stewards of this precious resource. The applications seem limitless, with effort focused on seafloor processes, ambient/manmade noise impacts, and ocean/seafloor dynamics. Data provided by these systems will empower scientists engaged in global climate studies to track and report accurately on trends in temperature changes. The density of emplaced sensors in these networks, when coupled with real-time data availability, enables higher resolution modeling and assessments of near shore processes.

Autonomous Underwater Vehicle (AUV) systems have evolved rapidly in the last decade as a viable means for ocean and seafloor mapping tasks. Fostered initially by government and academic interests, the systems have taken hold in the commercial realm, with an emphasis on energy exploration, as evidenced by the increased numbers in production. Government entities continue to drive some of the market with Exclusive Economic Zone and harbor defense survey requirements. Although the initial focus of applications is to enable accurate depictions of seafloor and sub-seafloor conditions, efforts to integrate AUVs into ocean observing networks have achieved some success in a number of venues. This application presents an opportunity to leverage and extend planned seafloor networks into deeper waters.

II. Background

Many existing systems can be broadly characterized as ocean observing networks. One of the longest running examples is the Drifting Buoy Program, with a worldwide system of surface floats (Fig. 1) that report via ARGOS satellite. The emphasis is primarily on surface or near surface weather conditions, but extension into the water column is realized with the use of attached sensing arrays such as thermistors and of profiling floats (e.g., APEX). Similarly, the U.S. National Data Buoy Center maintains a network of coastal and deep ocean moorings for weather observations. This effort has evolved to include seafloor observing capability in certain areas with the Tsunami Warning buoys.

III. Linked Networks

LEO-15 (Long Term Ecosystem Observatory at 15 meters), an effort sponsored under NOPP (National Oceanographic Partnership Program) is situated off the New Jersey coast (Fig. 2). The system was designed and implemented by Rutgers University and the Woods Hole Oceanographic Institution's (WHOI) Department of Applied Ocean Physics and Engineering [1]. This effort advanced the concept of AUVs for shallow water oceanographic observations by applying WHOI's REMUS 100 vehicle and docking station network for data

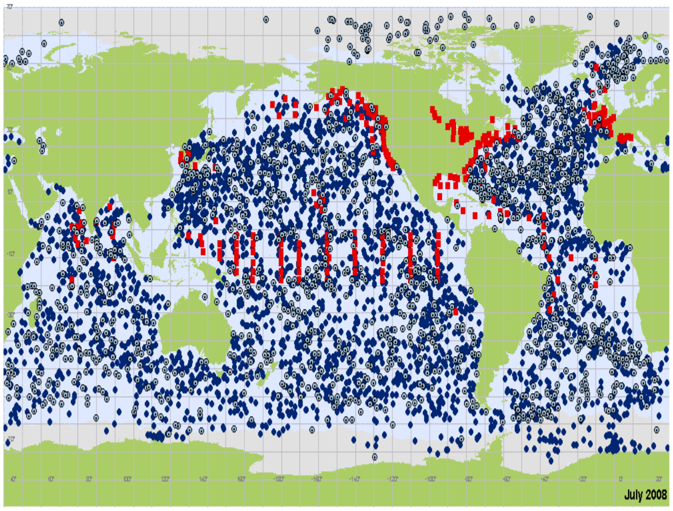

Figure 1. Floats and Drifting/Moored Buoy Locations [2]

transmission and vehicle charging. Data were assimilated with coastal radar and satellite imagery to describe near shore processes. Successful and repeatable docking via an Ultra Short BaseLine (USBL) acoustic system and periodic data transmission were significant accomplishments. LEO-15 has evolved into a more comprehensive Mid-Atlantic Observing System.

MARS (Monterey Accelerated Research System), NEPTUNE (North-East Pacific Time-Series Undersea Networked Experiments), and Regional Nodes associated with the latter are examples of planned and underway network installations occurring off the Pacific coast that extend beyond the shelf and into deep water. These represent aggressive and ambitious plans for true multiplexed networks that (a) incorporate seafloor networked sensors, (b) provide real-time connectivity for processed and raw data flow, and, as with LEO-15, (c) envision a future application of AUVs for investigation of oceanographic and geophysical phenomena. Fig. 3 depicts the Regional Node off Washington state.

The technology for installing, operating, and maintaining fiber, power, and multiplexing nodes on the seafloor is robust; however, it remains a high-cost endeavor. Moving optically

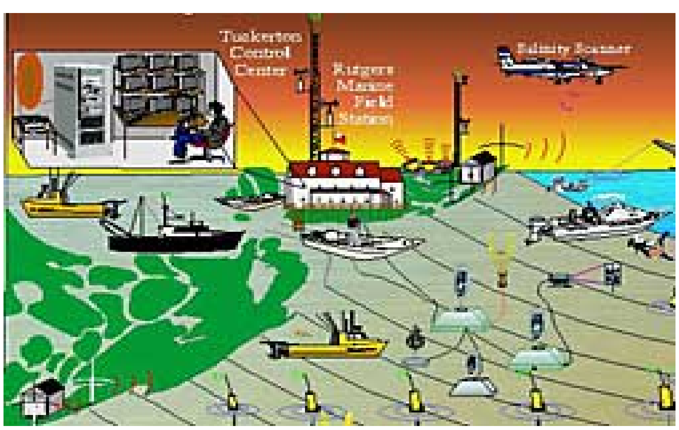

Figure 2. LEO-15 Observatory [3]

Figure 3. Regional Node, Ocean Observing Initiative [4]

linked networks into deep water (i.e., > 1000 m) dramatically increases costs, as the effort requires leasing of specialized ships, remotely operated vehicles, and custom work packages. Fig. 4 shows the MARS Science Node undersea junction that has been loaded into a trawl-resistant casing. At a nominal lease cost of $50 to $70K per day for ship, crew, and equipment (services), project costs can grow rapidly and could exceed $500K per installation or maintenance sortie. With this cost magnitude, system designers and sponsors are challenged to weigh the benefit of real-time networked reporting (and high resolution applications) against other approaches.

The use of non-network moorings can either serve as truly stand-alone networks, or, more likely, can be used to extend existing networks. This extension is made possible by the installation of an AUV docking station at an existing network node (similar to that employed by LEO-15, but for deep water). Recovery of data from these sensors in place is accomplished by the use of AUVs that serve in the role of data courier. The mode of data extraction from the sensor to the AUV will drive the configuration and operating characteristics of the mooring.

Figure 4. MARS Science Node (photo courtesy of MariPro, Inc.)

Acoustic Transmission: The current state of acoustic communications is such that acoustic performance has now achieved 200 kilobits per second (at ranges of 1 km) with advances in signal processing, direct sequence spread spectrum, and multiple input/output techniques [5]. Depending upon the data of interest, the sensor design must accommodate either onboard processing (i.e., current spectra or time series) or allow extraction (by the querying AUV) of discrete data sets as opposed to huge volumes of data.

Docked Data Transmission: For applications that require raw sensor data, designers may incorporate a docking mechanism in the mooring design. This complicates the sensor package, adding additional hardware and cost, but is certainly executable.

Although not the primary topic of this paper, ocean gliders are another technology with high potential for network data sharing and expansion using acoustic and satellite links. These systems, which can be characterized as a hybrid of profiling buoys and AUVs since they use passive propulsion (buoyancy changes), are steered with operator instructions during surfacing maneuvers. The number and use of gliders are multiplying rapidly with use in the research/development and Navy operational community.

IV. SUMMARY

Ocean Observing Networks that provide real-time links to shore-based facilities are being funded, planned, and installed along coastal regions worldwide. The NOAA Integrated Ocean Observing System (IOSS) web site lists the U.S. regional partners in the IOSS [6]. The resultant systems will enable unprecedented access to real-time data by potentially millions of people via web applications and allow scientists to assess short- and long-term changes in the ocean environment. AUV systems present a cost-effective opportunity to extend coverages of these networks between electro-optically cabled sensors and into deep ocean regions. Key enablers are found in existing technology and lessons learned, subsurface docking mechanisms, and acoustic transmission for data packet delivery. Advances in AUV endurance, proliferation of operational systems, and anticipated gains in data transfer (either acoustically or docked) will help to realize these goals.

REFERENCES

[1] S.M. Glenn, O. Schofield, R. Chant, J. Kohut, J. McDonnell, and S.D. McLean, "The LEO-15 Coastal Cabled Observatory—Phase II for the Next Evolutionary Decade of Oceanography," Proceedings of the 4th International Workshop on the Scientific Use of Submarine Cables and Related Technologies; Dublin, Ireland, February 2006.

[2] JCOMMOPS, JCOMM In-Situ Observing Platform Support Centre, 15 August 2008, http://wo.jcommops.org

[3] National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research, U.S. Government, 15 August 2008, http://www.oar.noaa.gov/spotlite/archive/spot_leo.html

[4] University of Washington, OOI Regional Component, NSF Ocean Observatories Initiative, 15 August 2008, http://www.ooi.washington.edu/

[5] Emma Jones, "Applying Software Radio Techniques to Underwater Acoustic Communication," *Sea Technology*, Vol. 49, No. 7, pp. 41-44, July 2008.

[6] National Oceanic and Atmospheric Administration (NOAA) Integrated Ocean Observing System (IOOS), U.S. Government, 15 August 2008, http://ioos.noaa.gov/partners/regional.html

Note: The inclusion of names of any specific commercial or academic product, commodity, or service in this paper is for informational purposes only and does not imply endorsement by the Navy or by NAVOCEANO.